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Particle Physics Division
Mechanical Department Engineering Note

Number: MD-ENG-341 Date: 28 May 2011

Project Internal Reference: None

Project: NOVA

Title: NOVA Ash River Pivoter Steering

Author(s): Dave Pushka

Reviewer(s): Kyle Beczkiewicz 6/22/11

Key Words: Ash River Pivoter Steering

Applicable Codes: None

Abstract Summary:

Pat Lukens, the physicist serving as the far detector installation manager, has requested that the pivoter be 'steered' to accommodate potential non-perpendicularity between the far wall of the Ash River detector building and the rails that the pivoter moves on.

This engineering note documents a design intended to satisfy Pat's request.

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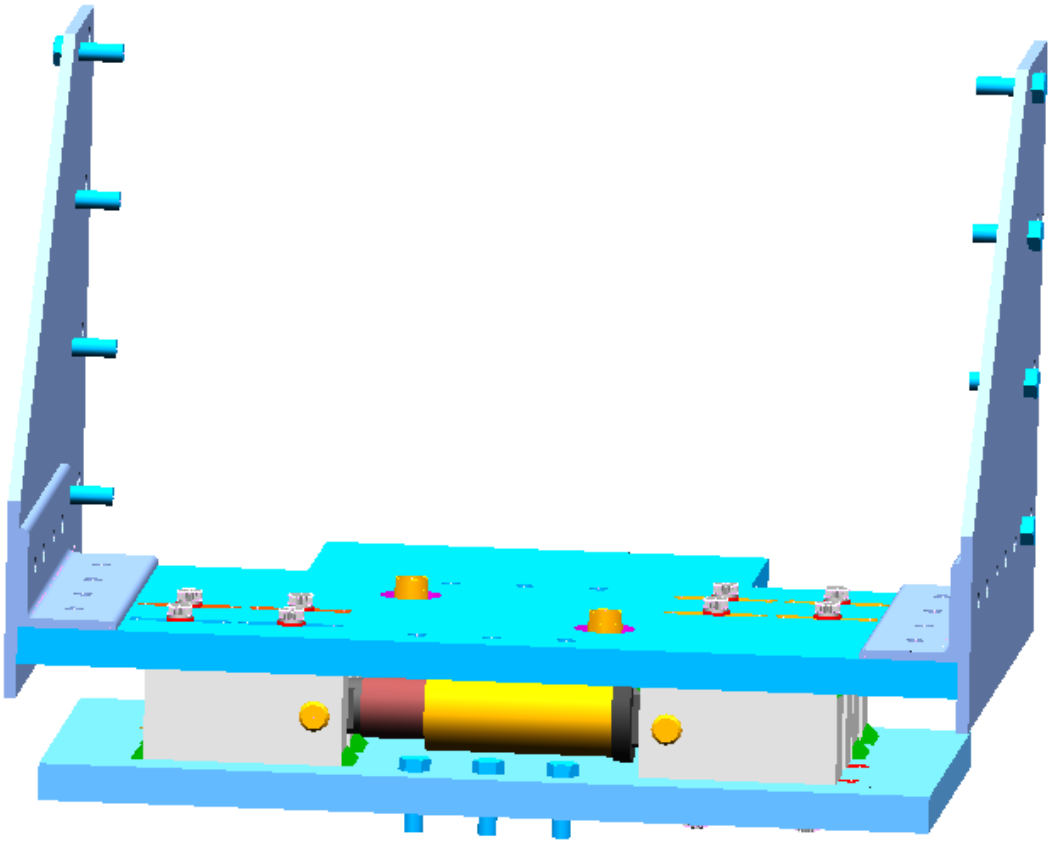
Image:



Discussion:

Design scheme is to move the back end of the pivoter laterally while keeping the front (end near the pallet) centered on the rail.

Rails installed as part of the building are 8 inches wide.

Cam-followers are located at the front and rear of the pivoter and were originally intended to keep the pivoter centered on the rails. Distance between the forward and rearward cam followers is 452 inches, center to center.

The 300 ton Hilman rollers used to support the pivoter have rollers that are 5 inches wide. Therefore, lateral displacements of the rollers in excess of plus or minus 1.5 inches will cause the roller to overhang the rail. This design will allow the Hilman roller to be moved approximately 1.5 inches to either side. 1.5 inch displacement over a lever arm of 452 inches results in a rotation of 0.2 degrees. For the table width of 620 inches, this results in a difference of just over 2 inches across the table width.

At the forward end of the pivoter, one set of cam-followers will need to be removed.

Cam followers have a maximum lateral load of 40,000 pounds.

Nominal vertical load of the Forward Hilman rollers is: 60,000 pounds
Nominal vertical load of the Center Hilman rollers is: 540,000 pounds
Nominal vertical load of the Rearward Hilman rollers is: 100,000 pounds

Refer to engineering note 320 for the source of these values. Exact values depend on the number of extrusions on the table, the orientation of the table (vertical, horizontal, or at some degree of rotation). Values in this engineering note represent the worst case values on each roller and do not necessarily occur at the same time. Specifically, the load on the rear Hilman rollers occurs when the table is unloaded and the values used for the Forward and Center Hilman Rollers occur when the table is fully loaded. Since the purpose of the steering is to align a detector block when it is vertical or very near vertical to the first bookend or previously set block, the loads on the Hilman rollers when the table is vertical will be used in sizing members.

Assumed static coefficient of friction of the hardened steel Hilman roller on the clean rail surface with a suitable lubricant is 0.20. Steel on steel coefficient of static friction varies from a high range near 0.8 to a low of 0.1 depending on the surface hardness and type of lubricant applied. Graphite, molybdenum disulfide and stearic acid are all suitable lubricants, capable of reducing the static sliding friction between the hard rail and the hard roller to less than 0.1. Paraffin oil is not as effective as a lubricant.

Stearic acid is a saturated fatty acid derived from animal fat and used in cosmetics, soaps, dietary supplements, and shaving cream.

Should the pivot need to be steered to align the table with the wall, the steering should be done while the drive hydraulics move the pivoter along the rails. Steering forces will be reduced significantly. This effect is much like a car without power steering is much easier to turn while it is in motion compared to turning the wheel while the car is parked.

Using a maximum vertical load on the rear Hilman roller of 100,000 pounds and a coefficient of static friction of 0.2, the required lateral force to move the pivoter frame is 20,000 pounds. Assume one frame pushed in one direction while a second pushes in the opposite direction, the net force required to shift the pivoter lower frames laterally would be 40,000 pounds.

40,000 pounds is the allowable load on the cam-follower.

Should the required lateral load exceed 40,000 pounds to shift the pivoter lower frame, both sides will need to be used to push in the same direction. Alternatively, the cam-follower that is pushed against can be replaced with a hard steel block with a higher load capability to allow the full 50,000 pound capacity of each cylinder to be used.

Use Sections 18, 19 and 20 in the spread sheet developed in engineering note 320 to determine the actual Hilman roller loads for load cases where the table is vertical and loaded with a block, the table is vertical and unloaded, and the table is horizontal and un-loaded. Use these Hilman roller loads and the coefficient of static friction of 0.2 to determine the required lateral force needed to shift the pivoter on the rails. Note that this is a statically indeterminate loading condition and the Hilman rollers can only restrain in the down direction (they do not prevent up-lift).

Distances, Loads and Steering Forces from Sections 18, 19 and 20 on the spreadsheet developed for Engineering note 320:

Front cam-followers to forward Hilman roller:	17	inches
Front cam-followers to center Hilman roller:	135	inches
Front cam-followers to rearward Hilman roller:	398	inches

Case 1, Table Vertical and Loaded with a Block

Load on forward Hilman rollers:	0	pounds
Load on center Hilman rollers:	954,626	pounds
Load on rearward Hilman rollers:	5,587	pounds

Case2, Table Vertical and Un-loaded

Load on forward Hilman rollers:	0	
Load on center Hilman rollers:	349,819	
Load on rearward Hilman rollers:	169,330	pounds

Case3, Table Horizontal, Unloaded

Load on forward Hilman rollers:	37,529	pounds
Load on center Hilman rollers:	316,745	pounds
Load on rearward Hilman rollers:	202,403	pounds

Case4, Table Horizontal, Loaded with a Block

Load on forward Hilman rollers:	3,571	pounds
Load on center Hilman rollers:	844,639	pounds
Load on rearward Hilman rollers:	112,000	pounds

Lateral Force to slide Hilman rollers across rails:

Case 1	35 tons
Case 2	13 tons
Case 3	12 tons
Case 4	31 tons

Therefore, the steering mechanism should be designed for capability in excess of 35 tons.

Design with the capability of using one hydraulic cylinder for each direction, each with 25 ton capacity. This gives 25 tons of lateral force for each steering mechanism, in excess of the cam follower capacity of 20 tons.

Using identical mechanisms on each lower weldment will provide lateral forces of about 50 tons, sufficiently in excess of the needed value.

Size welds on the blocks attached to the ends of each cylinder.

Design for P = 25 tons force, P = 50,000 pounds.

Blocks are 8 inches long, 2.5 inches wide. Assume welds on the ends of the blocks are designed to take the shear, therefore maximum weld length between two blocks and the plate is two times the block width times two blocks or 2* 2.5 * 2 = 10 inches.

Allowable weld shear load from AISC Connections volume, page 2-29 is given as:

P = 0.707 * width * length * 0.3 * Fy
Fy = 70,000 psi for E70XX filler metal
Allowable weld stress is 0.3 Fy = 21,000 psi (21 ksi).

Length $_{min}$ = P/(0.707 * 0.3125 * 0.3 * 70,000) = 10.8 inches

For a 5/16 inch fillet weld, the minimum required length is 10.8 inches
For a 3/8 inch fillet weld, the minimum required length is 9 inches.

Weld stress for a 3/8 weld with this loading is given by:
σ_{shear} = P / (0.707 * width * length) = 50,000 pounds / .707 * .375inches * 2 $_{blocks}$*2 $_{ends\ per\ block}$*2.5 $_{inches\ per\ block\ end}$ = 18.86 ksi.

Axis of the cylinder is 2 inches above the weld plane; therefore a moment is induced due to the eccentricity of 2 inches. Moment is 50,000 pounds * 2 inches = 100,000 in-lbs. Welds are 8 inches apart, therefore the tension on one weld due to the moment is 100, 000 inch – pounds / 8 inches is 12,500 pounds.

Minimum size of the fillet weld leg length to take this 12,500 pound load is given by:

Width $_{min}$ = P/(0.707 * 2.5 * 0.3 * 70,000) = 0.34 inches.

Weld stress for a 3/8 weld with this loading is given by:

$\sigma_{eccentric}$ = P / (0.707 * width * length) = 12,500 / .707 * .375 * 2.5 = 18.86 ksi.

Welds see a combined stress from the two loads. Shear is the square of the sum of the squares = square root (18.9^2 + 18.9^2) = 26.6 ksi. Therefore, the welds need to be larger than 3/8 inch fillet. Try ½ inch fillets:

Weld Stress due to Shear:
σ_{shear} = P / (0.707 * width * length) = 50,000 pounds / .707 * .5 inches * 2 $_{blocks}$*2 $_{ends\ per\ block}$*2.5 $_{inches\ per\ block\ end}$ = 14.1 ksi

Weld Stress due to Eccentric loading:
$\sigma_{eccentric}$ = P / (0.707 * width * length) = 12,500 / .707 * .5 * 2.5 = 14.1 ksi.

Weld Stress due to Combined shear and eccentric loading:

$\sigma_{combined}$ =SQRT ((σ_{shear})^2 + ($\sigma_{eccentric}$)^2) = 19.9 ksi

19.9 ksi < 0.3 * Fy therefore this weld size satisfies the strength criteria.

For 1.5 inch thick plate, the minimum fillet weld size is give in table J2.4 of the AISC code and is 5/16 inch for plate over ¾ inch in thickness.

Therefore, the ½ inch fillet weld meets the load and minimum weld size criteria.

Size pins used at the ends of the hydraulic cylinders:

Pin at the ends of the hydraulic cylinders are 1.25 inch in diameter. Shear area (assuming double shear) is 2.45 square inches. Load is 50,000 pounds. Shear stress is 20.4 ksi. Allowable shear stress is 0.4 Fy. Therefore, the minimum yield stress of the pin material is 50 ksi. ASTM A434 grade 4140 Turned, ground and polished material has a yield stress of 130 ksi.

Check the shear strength of the top plate where it extends into the lower weldment:

Top plate of the steering mechanism that bears against the lower weldment frame has a thickness of 1-1/2 inches, and must transfer a shear of 25 tons (50,000 pounds) by the 17.87 inch long tab extending into the lower weldment. Shear area is 1.5 * 17.87 = 26.8 square inches. Shear stress is 1865 psi. Allowable shear is 0.4 Fy per AISC. Minimum require material yield strength is 14 ksi. Nearly all steel is greater than 30 ksi, so almost any steel will work. Use A36.

Size the bolting used to connect this steering mechanism to the cam-follower support assemblies:

Bolting used to transfer the shear stress from the lower plate to the cam follower holder frame must carry 50,000 pounds. Six bolts are loaded in single shear with threads in the shear plane. Six ¾ -10 A325 bolts in single shear with threads in the shear plane have an allowable load of 63,600 pounds (10.6 kips per bolt per Table 7-1 in AISC 13th edition). Therefore, use six A325 (or grade 5) hex bolts for this connection.